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OBSERVATION AND ANALYSIS OF FE XVIII SOLAR X-RAY EMISSION.(U)

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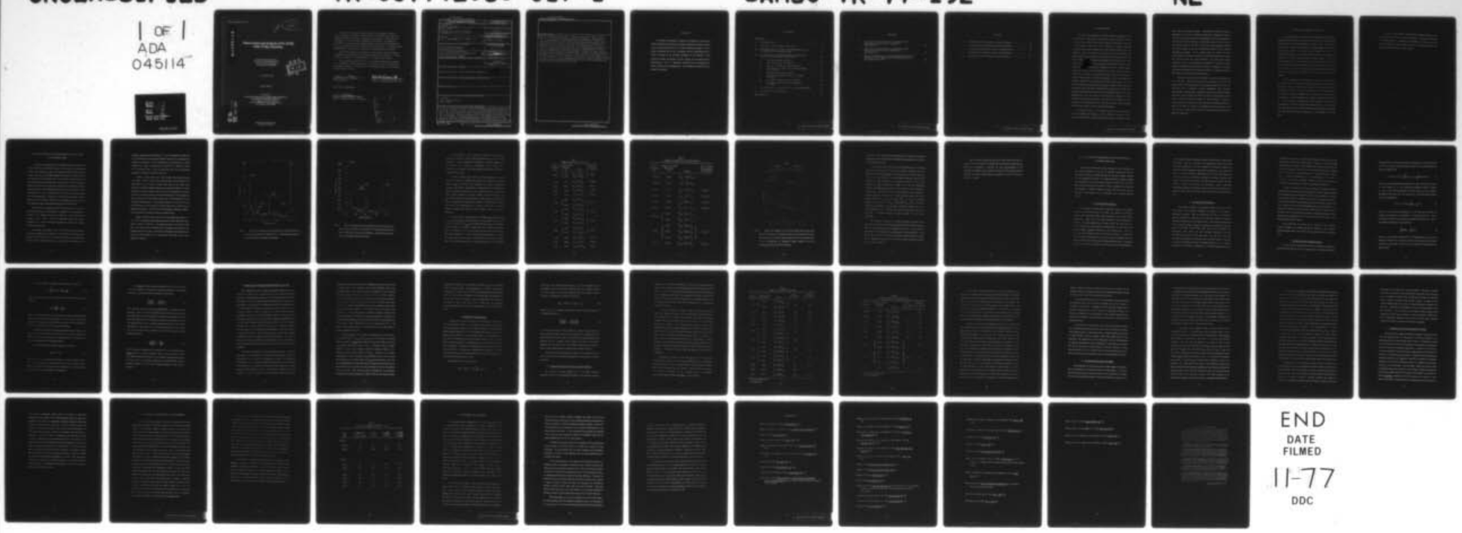

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Observation and Analysis of Fe XVIII Solar X-Ray Emission

Space Sciences Laboratory
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El Segundo, Calif. 90245

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Interim Report

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force Approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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X-ray spectra from the solar corona, obtained with a crystal spectrometer on the OV1-17 satellite, are used to analyze Fe XVIII emission lines between ~14 and ~16Å. The first comprehensive and accurate determinations of the coronal Fe XVIII wavelengths and relative intensities are made for the 2p-3d and 2p-3s transitions. Eighteen emission lines or line blends of Fe XVIII were observed and analyzed, including all X-ray lines previously observed in hot laboratory plasmas in this wavelength region. The measured OV1-17 wavelengths are in excellent agreement with the best laboratory measurements.

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20. ABSTRACT (Continued)

The relative intensities for the Fe XVIII lines are used to deduce relative effective collision strengths for a number of transitions. The potential effects of cascades, to the $2s^2 2p^4 3d$, 3p and 3s levels of Fe XVIII, on the interpretation of these relative collision strengths are discussed in detail. Calculations of the relative collision strengths using the modified Bethe approximation are compared to the OV1-17 deduced values. All 2p-3s values are observed to be substantially larger than predicted, probably indicating the important role played by cascades in populating the 3s levels. Agreement between the 2p-3s values is better, but not very good. Several explanations are offered for this discrepancy. Finally, the measured energy flux emitted in the X-ray region by the corona in the form of Fe XVII and Fe XVIII emission lines is compared for a variety of coronal conditions using the OV1-17 spectra. This comparison shows that accurate estimates of X-ray emission from hot astrophysical plasmas in the 14 to 16Å wavelength range must include contributions from Fe XVIII.

PREFACE

We should like especially to thank Dr U. Feldman for several very helpful discussions concerning the fluorine isoelectronic sequence spectra and for making available Dr. R. D. Cowan's oscillator strength and wavelength calculations for Fe XVIII. In addition, one of us (HRR) would like to thank Dr. Cowan for an extended discussion on the accuracy of the oscillator strength calculations and the validity of the modified Bethe approximation. Dr. D. L. McKenzie carefully read the manuscript and made a number of useful suggestions. We are grateful to Joanne Kari for typing the manscript.

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I. INTRODUCTION

The soft X-ray spectrum of the solar corona is dominated by the emission lines of high stages of ionization of iron during flares. In large flares, the density of lines from the 2p–3d and 2p–3s transitions in the ions Fe XVII through Fe XXIV has made it difficult to identify individual transitions in presently available flare X-ray spectra (Doschek, 1975). In addition to flare spectra, the X-ray spectra of hot active regions also display bright emission lines from the 2p–3d and 2p–3s transitions in Fe XVII and Fe XVIII. Detailed observations (Neupert, Swartz, and Kastner 1973, Walker, Rug[illegible]d Weiss 1974a, Parkinson 1975, Hutcheon, Pye, and Evans 1976) and [illegible] (Loulergue and Nussbaumer 1973, 1975, Walker, Rugge, and Weiss 1974a) of Fe XVII X-radiation from active regions have been carried out. However, no comprehensive and accurate observations of similar radiation from Fe XVIII are yet available. In the present paper we analyze a number of high resolution solar X-ray spectra taken from the OV1-17 satellite, including several taken after a moderate (class 1B) flare, in which we have been able to identify all of the principal Fe XVIII 2p–3d and 2p–3s transitions previously seen only in laboratory plasmas. The line identifications have been carried out using recent analyses of high resolution spark-excited laboratory X-ray spectra of Fe XVIII and have resulted in the clarification of the identity of several lines previously observed in the spectra of flares and hot active regions.

Theoretical models of the excitation of the spectrum of neon-like Fe XVII (Loulergue and Nussbaumer 1973, 1975) have resulted in good agreement between the predicted and observed relative intensities of the

2p-3d and 2p-3s transition arrays. Unfortunately, theoretical collision strengths for the more complicated fluorine-like isoelectronic sequence have not yet been calculated and, consequently, it has not been possible to calculate the relative intensities of the principal lines of the 2p-3d and 2p-3s transition arrays for Fe XVIII. Neither has it been possible to properly include the spectra of this ion in theoretical models of X-ray emitting astrophysical plasmas. In the present paper we present the first comprehensive and accurate evaluation of the relative intensities of all of the important 2p-3d and 2p-3s transitions in Fe XVIII under coronal conditions and use these intensities to calculate the relative effective collision strengths for these Fe XVIII transitions. In addition, we compare the relative contribution of Fe XVII and Fe XVIII X-ray intensities from the solar corona for a variety of plasma conditions.

Section II of this paper briefly describes the satellite experiment and the X-ray data. Section III discusses the observation of the Fe XVIII spectra, the Fe XVIII 2p-3d and 2p-3s wavelengths measured by the OV1-17 instrument and a comparison of these wavelengths with laboratory measurements of hot plasmas. Section IV concerns itself with the relative intensities of the strongest Fe XVIII lines and the determination of the relative effective collision strengths for these transitions. Section V briefly assesses the importance of Fe XVIII X-ray intensities compared to those of Fe XVII, the source of the strongest coronal X-ray lines from active regions. Finally, Section VI presents a summary of the paper and its principal conclusions.

II. THE OV1-17 SATELLITE X-RAY DATA

The data presented in this paper were obtained with an uncollimated Bragg crystal spectrometer experiment flown on the OV1-17 satellite which has been previously described (Walker and Rugge 1970). The experiment consisted of a solar pointer containing 3 scanning Bragg crystal spectrometers (KAP, EDDT, LiF crystals) which covered the 1.5 to 25Å wavelength interval. The Fe XVIII results described in this paper were obtained with the KAP (potassium acid phthalate) crystal and a photoelectric detector. The spectral resolution of the measurements is limited by the inherent line width attributable to the KAP crystal, if larger than 1.67 arc min., or by the on-board data sampling time (determined by the satellite telemetry) which corresponds to 1.67 arc min. of travel by the crystal.

The data presented in this paper were obtained on 1969 March 20 and 21, with much of the data used for detailed quantitative analysis having been taken about 70 minutes after a class 1B flare which occurred on March 21 at ~ 1330 UT. As a result, the majority of the Fe XVIII and other "hot" coronal X-ray lines originated from a small region on the solar disk. Consequently, the potential problem of artifically broadened spectral lines as a result of multiple strong sources, often encountered with full disk measurements of the sun using crystal spectrometers, is minimized for these data and the inherent instrumental spectral resolution is attained. This condition allows improved assignment of wavelengths for emission lines.

A total of eight spectra obtained under varying conditions of the solar coronal plasma were used in the evaluation of relative line intensities of Fe XVIII and in the comparison of Fe XVIII to Fe XVII line emission. Four of these eight spectral scans were taken consecutively, each scan requiring 4 minutes, after the class 1B flare.

III. DETERMINATION OF THE WAVELENGTHS OF THE Fe XVIII X-RAY EMISSION LINES

A number of experimenters have previously reported the observation of Fe XVIII emission lines from the solar corona (e.g., Evans, Pounds, and Culhane 1967, Neupert et al. 1967, Rugge and Walker 1968, Doschek, Meekins, and Cowan 1973, Walker, Rugge, and Weiss 1974b, Parkinson 1975, and Hutcheon, Pye, and Evans 1976.) Most of these reported spectra have been of relatively low resolution, with the exception of those of Parkinson (1975) and Hutcheon, Pye, and Evans (1976), both of which had excellent spectral resolution. Only Parkinson (1975) has attempted an analysis of the Fe XVIII lines to date. Unfortunately his Fe XVIII measurements suffer from low counting rates. However, he does present wavelength measurements for six Fe XVIII lines. Most of these wavelengths agree well with the best laboratory measurements (Feldman et al. 1973) of these lines.

We have used X-ray spectra of the Fe XVIII lines taken ~70 minutes after a class 1B flare on 1969 March 21 to determine the wavelengths of a number of the strongest lines or line blends of Fe XVIII which occur between ~14 to ~16Å. Over this wavelength region our spectral resolution was ~0.01Å, determined primarily by the OV1-17 satellite telemetry sampling rate.

The absolute wavelengths of the Fe XVIII lines were obtained by using the well-determined wavelengths of the Ne IX 1s-2p resonance line (13.447Å), the Fe XVII 2p-3d $^1P_1$ (15.012Å) and 2p-3s $^1P_1$ (16.769Å) lines and the constant and well-measured scanning rate of the potassium acid phthalate Bragg crystal (0.2500 deg s^{-1}). A total of eighteen Fe XVIII lines or line blends were observed with sufficient intensity to be unequivocally assigned a wavelength. The wavelengths were determined from a single spectral scan. Either the scan taken at 1442 UT or at 1446 UT on March 21 ($\sim$70 minutes after a class 1B flare) was used for the wavelength assignment of the great majority of the lines.

Figure 1 presents the sum of four spectral scans taken between $\sim$13.5 and $\sim$ 15.0Å. The four scans, taken between 1442 and 1458 UT on 1969 March 21, were added to better show some of the weaker lines. However, the addition slightly degrades the resolution available in a single spectral scan and, in addition, does not indicate the appropriate intensities of the Fe XVIII lines relative to the other strong lines as they appeared at 1442 UT, the time of the greatest emission of Fe XVIII radiation from the previously flaring region. The expected positions of the sixteen 2p–3d Fe XVIII lines, as well as those of several strong lines of other ions, are indicated in Figure 1. Four of the Fe XVIII multiplets indicated in Figure 1 are not resolved into individual lines by our spectrometer.

Figure 2 presents similar data for the wavelength region from $\sim$15 to $\sim$17Å. In this figure three spectral scans have been added; those from 1446 to 1458 UT on March 21. The expected positions of twelve Fe XVIII lines are shown, with the dashed lines indicating those blended with stronger lines of other ions. No attempt at wavelength determination was made for these blended lines. Strong lines from other ions are also indicated in Figure 2.

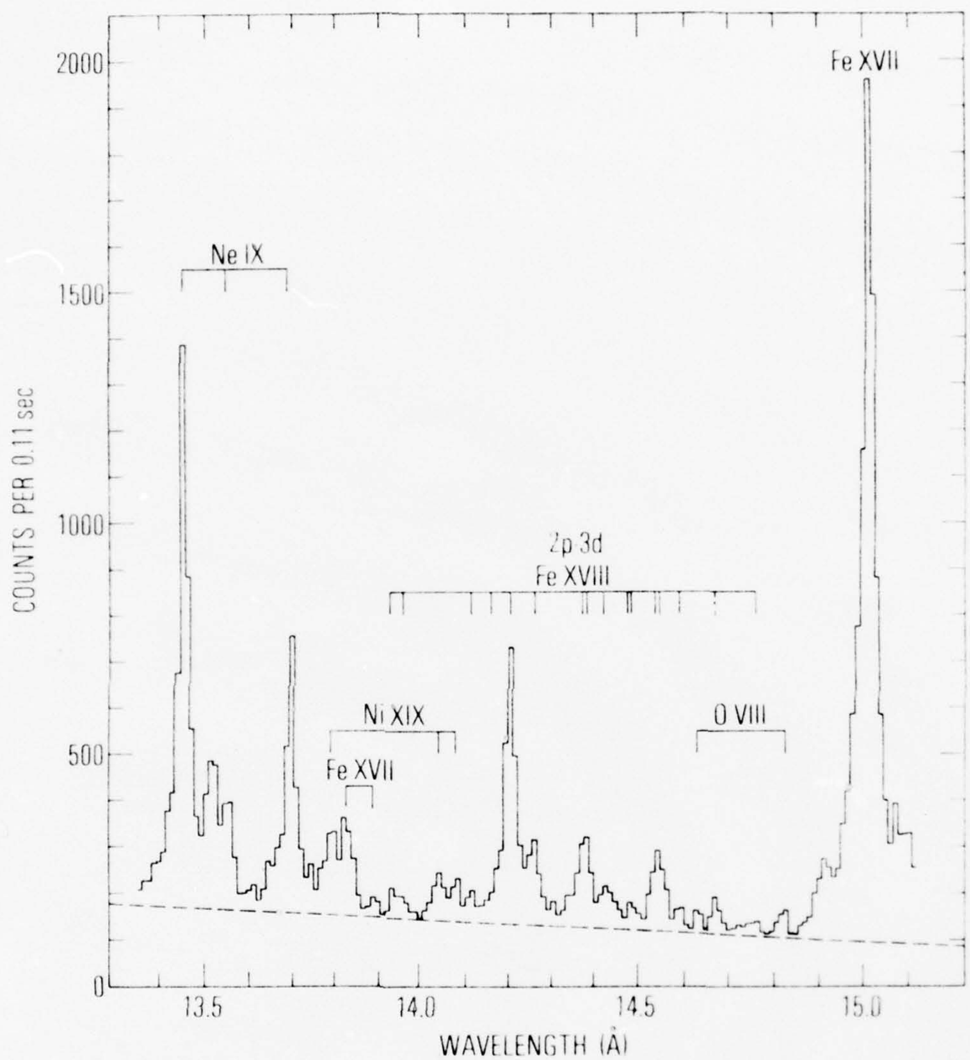

FIG. 1 - Sum of four spectral scans recorded by the KAP spectrometer on the OV1-17 satellite for 1969 March 21. The predicted positions of the Fe XVIII 2p-3d transitions are indicated.

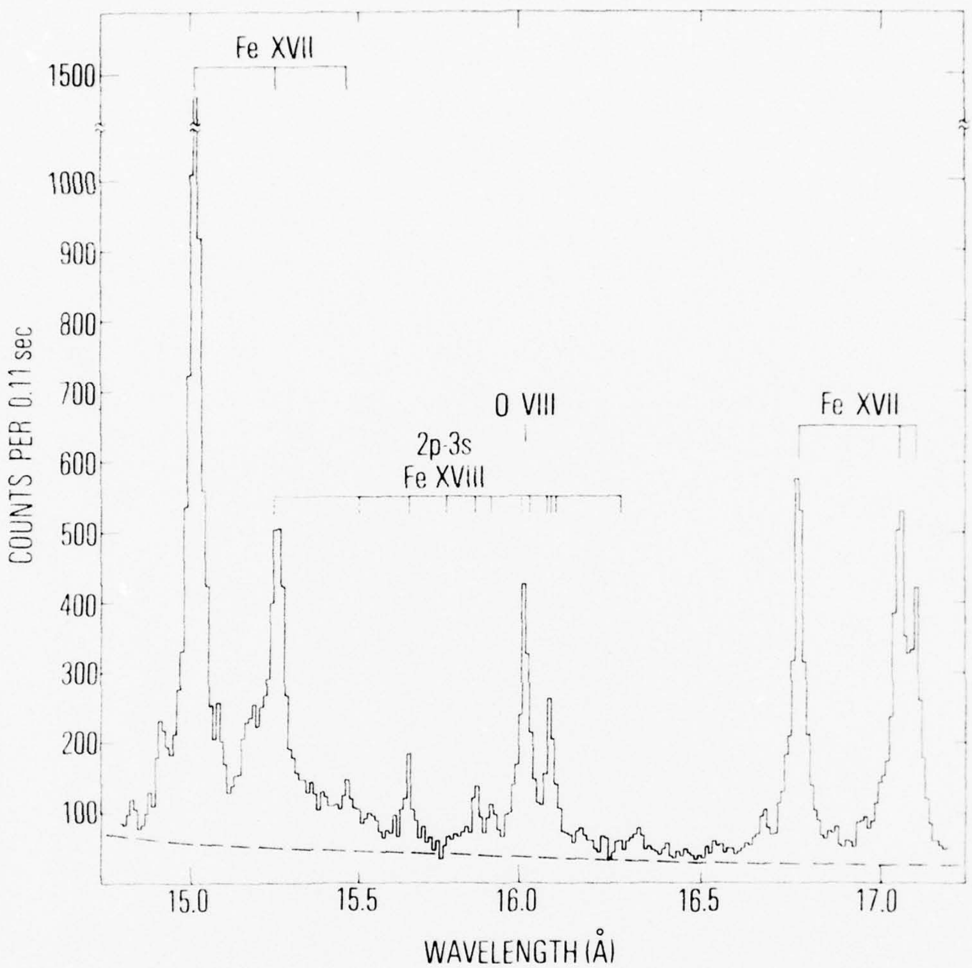

FIG. 2 - Sum of three spectral scans recorded by the KAP spectrometer on the OV1-17 satellite for 1969 March 21. The predicted positions of the Fe XVIII 2p-3s transitions are indicated. The dashed lines indicate blends with stronger lines of other ions.

The wavelengths of the Fe XVIII lines determined by our spectrometer are presented in Table 1 (2p-3d transitions) and in Table 2 (2p-3s transitions). The wavelengths are presented to 3 significant figures after the decimal. The uncertainty in wavelength for the stronger lines is estimated to be ± 0.005A. The other information presented in the tables is discussed below in § IV.

The most definitive work to date on the wavelengths of the emission lines of Fe XVIII in the 10-20Å region comes from the laboratory work of Feldman et al. (1973) who have considered the fluorine isoelectronic sequence in great detail. Earlier work on identification of Fe XVIII lines in laboratory plasmas was carried out, e.g., by Fawcett, Gabriel, and Saunders (1967), Cohen, Feldman, and Kastner (1968), Connerade, Peacock, and Speer (1970), Cohen and Feldman (1970), and Swartz et al. (1971). Some of these investigators have questioned a number of identifications made by others listed here, including some of Fe XVIII. At present, the paper of Feldman et al. (1973) seems to have resolved many of these past difficulties.

We have used the wavelength data of Feldman et al. (1973) for the 3s and 3d states which decay radiatively to the ground state term of Fe XVIII ($1s^2 2s^2 2p^5\ ^2P_{1/2, 3/2}$), and constructed the energy level diagram shown as Figure 3. It should be noted that not all possible upper level states are shown; but, for the most part, only those which gave rise to observable X-radiation. It should also be noted that although no 3p states are shown they do exist, lying in energy between 3s and the 3d states. However, since they cannot have an allowed transition to the $2p^5$ ground

TABLE 1

Fe XVIII 2p-3d Wavelengths and Intensity Ratios

OV1-17 Wavelength (Å)	Feldman et al. (1973) Wavelength (Å)	Transition	OV1-17 Intensity Ratio (Photons) $I(\lambda)/I(14.2\text{Å})$
13.943	13.919	$^2P_{3/2}-(^1S)3d\ ^2D_{3/2}$	0.20±0.02
	13.954	$^2P_{3/2}-(^1S)3d\ ^2D_{5/2}$	
14.118	14.121	$^2P_{1/2}-(^1S)3d\ ^2D_{3/2}$	0.08±0.02
14.151	14.150	$^2P_{3/2}-(^1D)3d\ ^2D_{3/2}$	0.10±0.04
14.200	14.200	$^2P_{3/2}-(^1D)3d\ ^2D_{5/2}$	1.00±0.025
14.254	14.255	$^2P_{3/2}-(^1D)3d\ ^2S_{1/2}$	0.36±0.02
14.368	14.361	$^2P_{1/2}-(^1D)3d\ ^2D_{3/2}$	0.43±0.02
	14.373	$^2P_{1/2}-(^3P)3d\ ^2D_{5/2}$	
14.422	14.419	$^2P_{1/2}-(^1D)3d\ ^2P_{3/2}$	0.25±0.015
	14.419	$^2P_{3/2}-(^3P)3d\ ^2F_{5/2}$	
14.474	14.467	$^2P_{1/2}-(^1D)3d\ ^2S_{1/2}$	0.11±0.01
	14.485	$^2P_{3/2}-(^3P)3d\ ^4P_{5/2}$	
14.541	14.536	$^2P_{3/2}-(^3P)3d\ ^4F_{5/2}$	0.40±0.02
	14.551	$^2P_{3/2}-(^3P)3d\ ^4P_{3/2}$	
14.589	14.581	$^2P_{3/2}-(^3P)3d\ ^4P_{1/2}$	0.13±0.015
14.660	14.666	$^2P_{1/2}-(^3P)3d\ ^2D_{3/2}$	0.16±0.015
14.761	14.772	$^2P_{1/2}-(^3P)3d\ ^4P_{3/2}$	0.12±0.02

TABLE 2

Fe XVIII 2p-3s Wavelengths and Intensity Ratios

OV1-17 Wavelength (Å)	Feldman et al. (1973) Wavelength (Å)	Transition	OV1-17 Intensity Ratio (Photons) I(λ)/I(14.2Å)
Blended	15.258	$^2P_{3/2}-(^1S)3s\ ^2S_{1/2}$	–
Blended	15.491	$^2P_{1/2}-(^1S)3s\ ^2S_{1/2}$	–
15.622	15.623	$^2P_{3/2}-(^1D)3s\ ^2D_{5/2}$	0.47±0.03
15.763	15.764	$^2P_{3/2}-(^3P)3s\ ^2P_{1/2}$	0.12±0.03
15.830	15.826	$^2P_{3/2}-(^3P)3s\ ^2P_{3/2}$	0.34±0.04
15.866	15.869	$^2P_{1/2}-(^1D)3s\ ^2D_{3/2}$	0.30±0.04
Blended	16.003	$^2P_{3/2}-(^3P)3s\ ^4P_{3/2}$	–
	16.024	$^2P_{1/2}-(^3P)3s\ ^2P_{1/2}$	
16.078	16.073	$^2P_{3/2}-(^3P)3s\ ^4P_{5/2}$	1.15±0.05
	16.087	$^2P_{1/2}-(^3P)3s\ ^2P_{3/2}$	
	16.109	$^2P_{1/2}-(^3P)3s\ ^4P_{1/2}$	
16.277	16.270	$^2P_{1/2}-(^3P)3s\ ^4P_{3/2}$	0.14±0.03

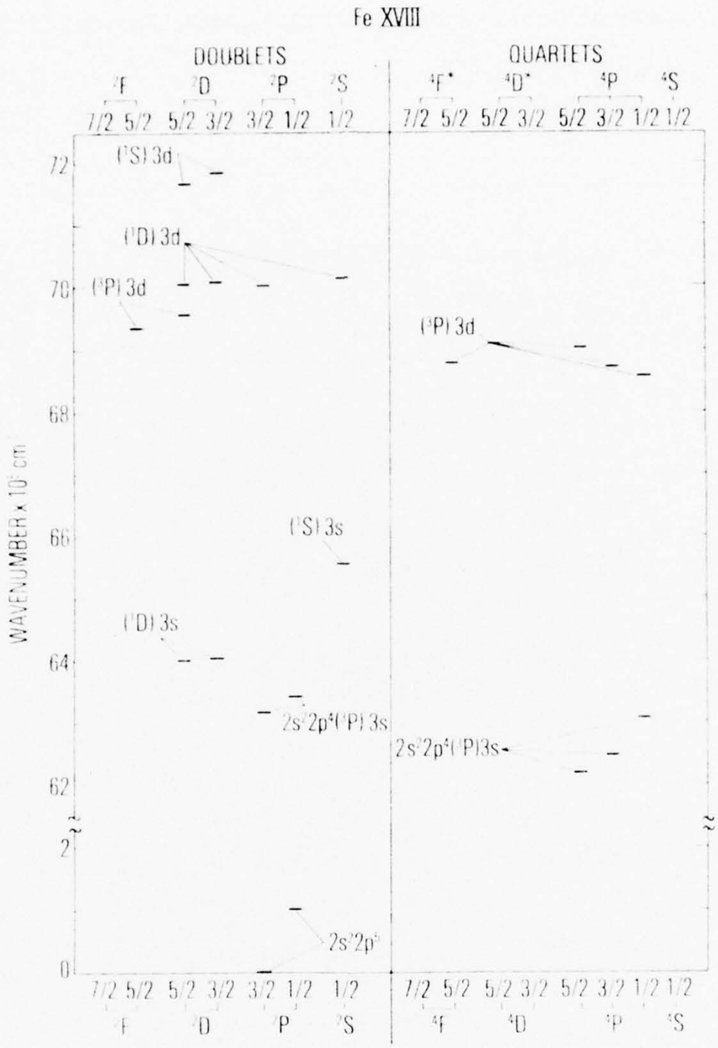

FIG. 3 - Energy level diagram for Fe XVIII showing those levels which give rise to observable X-radiation by decay to the ground state levels. The asterisks on the quartet states indicate that not all possible levels of this configuration are displayed because radiation from the undisplayed states has not been observed.

state levels of Fe XVIII, they instead populate the 3s levels by decaying to those states. The importance of this effect upon calculated line intensites will be discussed in § IV.

All of the Fe XVIII X-ray lines or line blends observed by Feldman et al. (1973) have been seen in the OV1-17 spectra, although several are sufficiently close in wavelength that they cannot be resolved from each other or, in a few cases, from blends with other strong lines. However, the majority of these multiple lines are obviously broader, in the OV1-17 spectra, than single emission lines. Tables 1 and 2 list the wavelengths measured by Feldman et al. (1973) for the 2p-3d and 2p-3s transitions, respectively. Also shown are the lower and upper levels assigned by Feldman et al. for each transition. In the Tables the lower level of the ground state term is given as either $^2P_{3/2}$ or $^2P_{1/2}$ to indicate, respectively, the $1s^2 2s^2 2p^5\ ^2P_{3/2}$ or $1s^2 2s^2 2p^5\ ^2P_{1/2}$ levels. The upper levels are abbreviated by, for example, listing the 14.200Å upper level $1s^2 2s^2 2p^4 (^1D)3d\ ^2D_{5/2}$ as $(^1D)3d\ ^2D_{5/2}$; the core electrons always being $1s^2 2s^2 2p^4$. A similar convention is used in Table 2 for the 2p-3s transitions.

The agreement between the Fe XVIII wavelengths measured by our spectrometer on the OV1-17 satellite and those measured by Feldman et al. (1973) in a laboratory plasma are excellent even for the weaker lines and well within the uncertainties of measurement for both experiments. This agreement, as well as the behavior of the lines measured during a variety of solar conditions, convinces us that all of the lines observed do indeed belong to the Fe XVIII ion.

One of the lines observed by the OV1-17 spectrometer and listed as a line of Fe XVIII in Table 1 at 14.660Å was not observed by Feldman *et al.* (1973) in the laboratory. However, the close correspondence of the measured wavelength to that calculated for the Fe XVIII transition and its behavior with solar activity leads us to believe it is an Fe XVIII line as indicated in Table 1.

IV. Fe XVIII RELATIVE INTENSITIES AND RELATIVE EFFECTIVE COLLISION STRENGTHS

This section discusses the relative intensites of the Fe XVIII lines (or line blends) measured by the OV1-17 satellite spectrometer and the relationship of those measured intensities to effective collision strengths for the appropriate transitions. The deduced effective collision strengths are compared to the only available calculations which make use of the Bethe approximation and the results of such a comparison are presented and discussed. Potential problems arising from line blends are also discussed in this section, as is a comparison with previously obtained results.

a) Fe XVIII Relative Intensities

The measured Fe XVIII photon intensities relative to the photon intensity of the Fe XVIII line at 14.200Å, the strongest Fe XVIII line observed, are presented in Table 1 (2p-3d transitions) and in Table 2 (2p-3s transitions). These ratios and their uncertainties were determined as follows: For each spectral scan in which a given line was visible, its relative intensity was determined by correcting the counts in each line by the wavelength dependent efficiency of the spectrometer. (This is a relatively small correction since all the lines lie between ~ 14 and 16Å.) The uncertainty attributable to each line was that associated with the counting statistics of that line and its background subtraction. A weighted average of the relative intensity for each line was then obtained using all of the spectral scans (a maximum of eight) in which that line was clearly discernable. All but the weakest lines appeared in most of the eight available spectral scans. Five of the eighteen Fe XVIII lines observed had intensities (after background subtraction) represented by more than 1000 counts, four had intensities represented by less than 200 counts; the remaining lines had intensities represented by between 200 and 1000 counts. For the four lines with the lowest number of counts (14.118Å, 14.151Å, 15.763Å and 16.277Å), the uncertainties owing to decisions concerning background subtraction and limits of spectral integration are probably greater than those shown, which result from counting statistics only.

b) Past Theoretical Calculations

The primary mechanism for populating excited levels in Fe XVIII, which lead to the radiative transitions of interest in this paper, is collisional excitation. Thus, to calculate the Fe XVIII X-ray intensities collision strengths are required, as are oscillator strengths to calculate radiative branching ratios from excited states. While detailed calculations of the collision strengths required to calculate the collisional excitation rates in neon-like Fe XVII have been carried out (Loulergue and Nussbaumer 1973, 1975), the more difficult fluorine-like Fe XVIII calculations have not yet been attempted. For the case of Fe XVII Loulergue and Nussbaumer (1973) first used a 36 level scheme to describe the statistical equilibrium equations including terms up to $n = 3$. A similar calculation for Fe XVIII, i.e., including all $n = 3$ levels, would necessitate a calculation with 92 levels. Loulergue and Nussbaumer (1975) have recently carried their Fe XVII calculations further to include n = 4 levels, adding another 89 levels. However, they included only a total of 51 Fe XVII levels in their line intensity calculations and found only relatively minor changes from the results of the 36 level (up to n = 3 only) calculations. Until at least a complete calculation up to and including the n = 3 levels is completed, a detailed comparison between measured and calculated Fe XVIII X-ray line intensities cannot be meaningfully carried out.

Tucker and Koren (1971) have estimated the "summed" collision strengths for the 2p-3d and 2p-3s transitions in Fe XVIII. These estimates were obtained by scaling the collision strengths for boron-like ions. In turn, the boron-like collision strengths were obtained by using calculations of Bely and Petrini (1970) for the excitation of 2p-nl transitions in lithium-like ions. Inasmuch as the Fe XVIII wavelengths and correct designations of a number of levels were not well known at the time of the work of Tucker and Koren (1971) and because only an order of magnitude accuracy can be expected, these calculations do not serve as an effective check on any experimentally obtained results.

Kato (1976) has also carried out an estimate of the "summed" collision strength for Fe XVIII using similar techniques. His "summed" collision strength differs from that of Tucker and Koren (1971) by a factor of 20.

c) Effective Collison Strength Definition

The basic theory of collisional excitation and subsequent radiation of coronal ions has been put forth, for example, by Van Regemorter (1962).

Using this theory it can be shown that the energy flux at the earth, E (ergs $cm^{-2}s^{-1}$), for a given transition between states j and i may be written as: (see, e.g., Walker 1972)

$$E \simeq 3.05 \times 10^{-33} E_{ij} \frac{\bar{\Omega}_{ij}}{\omega_i} B_{ji} a_H A_Z \int G(T)\, M(T)\, dT \qquad (1)$$

where E_{ij} is the energy difference between the upper (j) level and the lower (i) level (ergs), $\bar{\Omega}_{ij}$ is the temperature-averaged collision strength, $\omega_i = 2J_i+1$ is the statistical weight of the lower state, a_H is the number of hydrogen ions per electron in the plasma, A_Z is the elemental abundance relative to hydrogen and

$$G(T) = T^{-1/2} \exp\left(-\frac{E_{ij}}{kT}\right) a_{Zz}(T) \qquad (2)$$

where T is the electron temperature, k is the Boltzmann constant and $a_{Zz}(T)$ is the fraction of the element Z in ionization stage z (z = 18 for Fe XVIII) determined from ionization equilibrium considerations. M(T) is the differential emission measure given by

$$\int M(T)dT = \int n_e^2 dV \qquad (3)$$

where n_e is the electron density (cm^{-3}). The branching ratio, B_{ji}, must be included if excitation from the ground level i to the upper level j can result not only in a decay back to level i but also to another level lying below the upper (j) level.

$\bar{\Omega}$, the temperature-averaged collision strength is defined by

$$\bar{\Omega} = \int_0^\infty \Omega\,(E) \exp\left(-\frac{E}{kT}\right) d\left(\frac{E}{kT}\right) . \tag{4}$$

$\Omega(E)$ is related to the cross section for collisional excitation from state i, $\sigma\,(E)$, by

$$\sigma\,(E) = \frac{\pi \hbar^2}{2mE} \cdot \frac{\Omega\,(E)}{\omega_i} , \tag{5}$$

where m is the electron mass, E the energy of the incident electron and the other symbols have their usual meaning. Since Ω is usually only weakly dependent on energy near threshold (see, e.g., Walker 1972) the approximation is often made that $\bar{\Omega} \simeq \Omega$ evaluated at threshold.

It should be noted that the collision strength defined by eqns. (1), (4) and (5) is the usual definition, but differs from that used by Tucker and Koren (1971) in that they include the statistical weight of the initial state, ω_i, in their definition of the collision strength.

The effective collision strength, Ω_{eff}, can be defined as

$$\Omega_{eff} = \bar{\Omega} \cdot B_{ji} . \tag{6}$$

Thus, when a radiative transition from level j to i results only from level j being filled by collisional excitation from level i (the so-called coronal excitation condition), the effective collision strength may be deduced from the line intensity by use of equations (1) through (6).

The relative effective collision strength for two lines from the same ion may be obtained in terms of the measured intensities of the relevant transitions (1 and 2) of interest from equations (1) and (6) as

$$\frac{\Omega_{eff}(1)}{\Omega_{eff}(2)} \simeq \frac{\omega_1 E_1 \lambda_1}{\omega_2 E_2 \lambda_2} . \tag{7}$$

where we have assumed the integral $\int G(T)M(T)dT$ is identical for both transitions. The ωs are the statistical weights of the lower levels of the transitions and the λs the wavelengths of the relevant transitions. In fact, since G(T) contains a term involving the energy of the transition (see eq. 2) this approximation is only valid when comparing transitions with similar wavelengths as is the case for the Fe XVIII transitions of interest here. The same ratio can also be obtained in terms of the measured photon intensity, I, ratio as

$$\frac{\Omega_{eff}(1)}{\Omega_{eff}(2)} \simeq \frac{\omega_1 I_1}{\omega_2 I_2} . \tag{8}$$

For the purpose of this paper we use equation (8) as the definition of the relative effective collision strength. Thus, we may use the measured Fe XVIII photon intensities relative to the 14.200Å Fe XVIII transition given in Tables 1 and 2 to calculate directly the Fe XVIII effective collision strengths relative to the effective collision strength for the 14.200Å transition.

d) Interpretation of Effective Collision Strength for Fe XVIII

The interpretation of the effective collision strength for an ion as complex as Fe XVIII is not as simple as for an ion in which the coronal excitation condition applies rigorously. There are two primary reasons for the departure from this straightforward interpretation; (1) cascades (very probably) play an important role in populating a number of important levels of Fe XVIII, and (2) Fe XVIII has two ground state levels ($^2P_{3/2}$ and $^2P_{1/2}$ - see Fig. 3) both of which can serve as the lower level in radiative transitions, but only one of which effectively serves as the lower level for collisional excitation ($^2P_{3/2}$). Thus, while the operative definition of the relative effective collision strength (Equation 8) in terms of the observed radiation from a given transition will yield the appropriate relative intensity ratio for a hot, optically thin astrophysical or laboratory plasma, it will not necessarily provide accurate results if the relative collision strengths are used for collisonal excitation calculations. The lack of accuracy, for various transitions, will vary directly with the importance of the two conditions given above relative to that of the coronal excitation condition.

Although no calculations have been performed to date, it is anticipated that cascades will play a significant role in populating a number of important levels in Fe XVIII. This conclusion is reached by analogy with the situation for Fe XVII where detailed calculation have been performed theoretically and a comparison has been made with experimental results (Loulergue and Nussbaumer, 1975). In Fe XVII the strongest effect of cascades is on the 3s states. For this ion only a few percent of the population of the 3s levels arises from collisional excitation directly from the ground state. The majority of the 3s level population arises from cascades from 3p levels, many of which are populated, in turn, by cascade from the 3d levels. A similar set of 3p levels exist in Fe XVIII. States in which a 2s electron, rather than a 2p electron, is excited can also lead to cascades to the $2p^4 3d$, 3p and 3s levels in Fe XVIII. In view of these results for Fe XVII, it seems reasonable that these same mechanisms may operate for Fe XVIII to some degree. To the extent that they do operate, the usefulness of the relative effective collision strengths, inferred from radiative intensities, for collisional excitation calculations is diminished. It is anticipated, by analogy with Fe XVII, that the effect will be greatest for the 3s states. Some evidence for that view is presented in § IV f. The cascade effect may also affect the 3p states, but its importance cannot be properly assessed at this time.

Another difficulty for Fe XVIII is the presence of two ground state levels, the $1s^2 2s^2 2p^5\ ^2P_{3/2}$ and $^2P_{1/2}$ (see Fig. 3). Radiative transitions from upper levels to <u>both</u> ground state levels occur (see Tables 1 and 2) and thus equation (8) may be used to infer an effective collision strength (relative to the 14.2Å transition effective collision strength) for a transition having a ground state level $^2P_{1/2}$. However, the excitation which gave rise to this transition in all probability did not arise from this ground state level but rather from the $^2P_{3/2}$ ground state level. This may be easily demonstrated by approximating the situation by assuming the two ground levels form a two-level ion and calculating the relative populations of the two levels. The necessary collision strength may be accurately extrapolated from data presented by Blaha (1969) and the magnetic dipole transition probability for the transition obtained, e.g., from Petrosian (1970) or Kastner (1976). If a temperature of $\sim 5 \times 10^6$K is assumed (the variation with T goes only as $T^{-1/2}$), the electron density must exceed 10^{12} cm^{-3} before even one percent of the ground state ions populate the $^2P_{1/2}$ level. Thus the effective collision strength ratios for transitions involving the $^2P_{1/2}$ ground level have meaning only for calculating radiative intensity ratios, and not for collisional excitation from that $^2P_{1/2}$ state.

e) Modified Bethe Approximation

Although no detailed calculations on the collisional excitation of Fe XVIII have been carried out an approximation, which is often used, relates the collision strength to the oscillator strength. This is the Bethe approximation modified by use of the averaged Gaunt factor, $\bar{g}$, as introduced by Seaton (1962) and Van Regemorter (1962). This approximation is only valid for allowed transitions and at high energies, where the short-range interaction between the perturbing electron and the atomic electron may be neglected. Although this modified Bethe approximation has been extensively used in astrophysics, straightforward application of the $\bar{g}$ empirical formula may give considerable error for cross section determinations (Bely and Van Regemorter 1970).

The approximation may be written as

$$\Omega_{eff} \approx \frac{8\pi}{\sqrt{3}} \omega_i f_{ij} \bar{g}_{ij} \frac{\lambda_{ij}}{hc} I_H B_{ji} , \tag{9}$$

where $\bar{g}_{ij}$ is the averaged Gaunt factor, λ_{ij} is the wavelength of the transition, h and c have their usual meaning, f_{ij} is the oscillator strength, I_H is the Rydberg and the other parameters have been defined earlier in this paper. Evaluating the constants one obtains,

$$\Omega_{eff} \approx 0.0159 \quad \omega_i f_{ij} \bar{g}_{ij} \lambda_{ij} B_{ji} \tag{10}$$

where λ_{ij} is in Å. Therefore the ratio of effective collision strengths for two transitions 1 and 2 is

$$\frac{\Omega_{eff}(1)}{\Omega_{eff}(2)} \approx \frac{\omega_1 f_1 \lambda_1 B_1}{\omega_2 f_2 \lambda_2 B_2} \quad . \tag{11}$$

It is assumed the averaged Gaunt factors are equal for the two transitions. This assumption, often made, must be used since no calculations of the Gaunt factor exist for Fe XVIII. Mewe (1972) has presented interpolation formulae for the averaged Gaunt factors for several isoelectronic sequences, but not that of FI. In any case he treats only excitation to atomic levels without taking into account their multiplet structure.

Thus, relative effective collision strengths may be approximated by use of equation (11) if the oscillator strengths for the transitions of interest are known.

f) Results for the Relative Effective Collision Strengths

The effective collision strengths for the Fe XVIII transitions measured by the OV1-17 spectrometer relative to the effective collision strength for the strong Fe XVIII line at 14.2Å may be obtained directly by using equation (8) and the listed intensity ratios of the transitions given in Tables 1 and 2. The results are given in Tables 3 and 4 for the 2p-3d and 2p-3s transitions, respectively. The values with the asterisks are those line blends for which the collision strengths had to be weighted because of an admixture of the two ground state levels in the blend. This is discussed in the next sub-section.

We have attempted to compare these experimentally obtained results with calculations based on the modified Bethe approximation by using equation (11). In order to carry out this calculation the oscillator strengths and branching ratios, which can be derived from the oscillator strengths, are required. Dr. R. D. Cowan has previously calculated the (unpublished) required oscillator strengths for Fe XVIII using Hartree-Fock wave functions in a manner similar to his earlier calculations (Cowan 1967, 1968) for use in the paper by Feldman et al. (1973). Dr. Feldman has kindly made these calculations available to us. Using Cowan's oscillator strengths and the transition designations of Feldman et al. (1973) we have calculated the relative collision strengths for both the 2p-3d and 2p-3s transitions. The results are shown in the last column of Table 3 and 4, respectively.

Examination of Table 4 shows that all values of the collision strength ratios calculated by the Bethe approximation are substantially below their measured values. We believe this is strong evidence to indicate that the role of cascades from the 3p levels to the 3s levels is as important in Fe XVIII as in Fe XVII. If this is indeed the case a meaningful comparison between the two sets of values cannot be made.

TABLE 3

Fe XVIII 2p 3d Effective Collision Strength Ratios

OV1-17 Wavelength (Å)	Feldman et al. (1973) Wavelength (Å)	Transition	OV1-17 $\Omega_{eff.}(\lambda)/\Omega_{eff.}(14.2Å)$	Calculated† $\Omega_{eff.}(\lambda)/\Omega_{eff.}(14.2Å)$
13.943	13.919 13.954	$^2P_{3/2}-(^1S)3d\ ^2D_{3/2}$ $^2P_{3/2}-(^1S)3d\ ^2D_{5/2}$	0.20	0.06
14.118	14.121	$^2P_{1/2}-(^1S)3d\ ^2D_{3/2}$	0.04	0.45
14.151	14.150	$^2P_{3/2}-(^1D)3d\ ^2D_{3/2}$	0.10	0.03
14.200	14.200	$^2P_{3/2}-(^1D)3d\ ^2D_{5/2}$	1.00	1.00
14.254	14.255	$^2P_{3/2}-(^1D)3d\ ^2S_{1/2}$	0.36	0.21
14.366	14.361 14.373	$^2P_{1/2}-(^1D)3d\ ^2D_{3/2}$ $^2P_{1/2}-(^3P)3d\ ^2D_{5/2}$	0.22	0.73
14.422	14.419 14.419	$^2P_{1/2}-(^1D)3d\ ^2P_{3/2}$ $^2P_{3/2}-(^3P)3d\ ^2F_{5/2}$	0.20 *	0.04
14.474	14.467 14.485	$^2P_{1/2}-(^1D)3d\ ^2S_{1/2}$ $^2P_{3/2}-(^3P)3d\ ^4P_{5/2}$	0.06 *	0.01
14.541	14.536 14.551	$^2P_{3/2}-(^3P)3d\ ^4F_{5/2}$ $^2P_{3/2}-(^3P)3d\ ^4P_{3/2}$	0.40	0.38
14.589	14.581	$^2P_{3/2}-(^3P)3d\ ^4P_{1/2}$	0.13	0.05
14.660	14.666	$^2P_{1/2}-(^3P)3d\ ^2D_{3/2}$	0.08	—
14.761	14.772	$^2P_{1/2}-(^3P)3d\ ^4P_{3/2}$	0.06	< 0.01

* Blend with mixed ground level

† Bethe Approximation

TABLE 4

Fe XVIII 2p-3s Effective Collision Strength Ratios

OV1-17 Wavelength (Å)	Feldman et al. (1973) Wavelength (Å)	Transition	OV1-17 $\Omega_{eff.}(\lambda)/\Omega_{eff.}(14.2Å)$	Calculated† $\Omega_{eff.}(\lambda)/\Omega_{eff.}(14.2Å)$
Blended	15.258	$^2P_{3/2}-(^1S)3s\ ^2S_{1/2}$	—	< 0.01
Blended	15.491	$^2P_{1/2}-(^1S)3s\ ^2S_{1/2}$	—	0.01
15.622	15.623	$^2P_{3/2}-(^1D)3s\ ^2D_{5/2}$	0.47	0.06
15.763	15.764	$^2P_{3/2}-(^3P)3s\ ^2P_{1/2}$	0.12	0.01
15.830	15.826	$^2P_{3/2}-(^3P)3s\ ^2P_{3/2}$	0.34	0.02
15.866	15.869	$^2P_{1/2}-(^1D)3s\ ^2D_{3/2}$	0.15	0.05
	16.003	$^2P_{3/2}-(^3P)3s\ ^4P_{3/2}$		
Blended			—	0.08
	16.024	$^2P_{1/2}-(^3P)3s\ ^2P_{1/2}$		
	16.073	$^2P_{3/2}-(^3P)3s\ ^4P_{5/2}$		
16.078	16.087	$^2P_{1/2}-(^3P)3s\ ^2P_{3/2}$	1.14*	< 0.01
	16.109	$^2P_{1/2}-(^3P)3s\ ^4P_{1/2}$		
16.277	16.270	$^2P_{1/2}-(^3P)3s\ ^4P_{3/2}$	0.07	< 0.01

*Blend with mixed ground level

† Bethe Approximation

For the 2p-3d transitions (Table 3), even for the stronger lines, the agreement is generally not too good with differences between the Bethe-approximation calculation and the measured ratios being up to a factor of three. For some of the weaker lines the difference is even larger. The worst case is for our weak 14.118Å line where the measured ratio is ~10 times smaller than the theoretical prediction. For this case, as has been done for all the other lines if possible, we have checked other available data for the relative line strengths and find general agreement with our measured values as opposed to the Bethe-approximation calculations.

We have used the visually estimated (from film) Fe XVIII relative line strengths as qualitatively presented by Feldman et al. (1973) to discern strong from weak lines in their plasma, the conditions of which may have differed considerably from those in the solar corona at the time of our measurements. Qualitatively our results agree with theirs. Hutcheon, Pye and Evans (1976) have published a high resolution X-ray spectrum of the corona, also taken about 1 hour after a small flare. Unfortunately they have only provided the intensity ratios of a number of Fe XVII lines. Their spectra are quite similar to ours for the time period from 1442 to 1458 UT on 1969 March 21. Therefore, we have used their spectra as shown, and also information provided in their paper concerning the efficiency of their Bragg spectrometer, to make estimates of the relative intensities of those Fe XVIII 2p-3d lines we could easily observe in their spectra. The semi-quantitative results we obtain are in excellent agreement with our relative intensities for the 2p-3d transitions. We therefore conclude this is further evidence that our measured line intensities, on which the experimental relative effective collision strengths are based, are correct and any disagreements with calculations based on the modified Bethe approximation result from one or more of three potential difficulties.

The first possible reason for the disagreement between calculated and measured 2p-3d relative collision strengths may be the influence of cascades on the 3d levels. Although the effect should be smaller than on the 2p-3s transitions of Fe XVIII, Table 4 dramatically illustrates the effects of cascades for 2p-3s transitions. Until detailed calculations are performed, the influence of cascades on the 3d levels of Fe XVIII cannot be properly assessed.

The second and third potential reasons for the discrepancy between the measured and calculated values in Table 3 have to do with the modified Bethe approximation. As mentioned earlier, the approximation is only valid at "high" incident electron energies, where short-range forces can be neglected. The temperature in the coronal plasma may not be high enough to make this approximation valid. Additionally, it was necessary to assume that the $\bar{g}$s were equal for all transitions. Variations of $\bar{g}$ from its usual assumed value of ~ 0.2 of a factor of two or three are observed (see, e.g., Mewe 1972) and may also account for some of the discrepancies in Table 3.

g) Potential Problems with Line Blends

The possibilities of blended lines add a further degree of complication to the analysis of the already complex Fe XVIII analysis. A first, and relatively minor, problem was mentioned in the last sub-section. In Tables 3 and 4, three line blends (14.422Å, 14.474Å, 16.078Å) have admixtures of the two ground state levels ($^2P_{3/2}$, $^2P_{1/2}$) as their lower level. Therefore, the application of equation (8) is not straightforward since a value must be assigned for the statistical weight of the lower level of the transition. For these three cases we have weighted the contribution to each blend by the value the theory, based on the Bethe approximation, would give to each. This approximation may be somewhat valid for the 2p-3d transitions, but should not be expected to be as good for the 2p-3s transitions because of the cascading effects from the 3p levels, discussed above, which it is not possible to take into account properly in this procedure. However, the maximum error introduced by this uncertainty is a factor of 2, the ratio of the statistical weights of the two ground state levels.

A potentially more important problem occurs because of the possibility of other Fe XVIII transitions lying sufficiently close in wavelength to observed Fe XVIII lines to form unresolved blends. Feldman et al. (1973) discuss this possibility in their work on the fluorine isoelectronic sequence. They find that this difficulty may exist for three Fe XVIII excited levels which have the $2p^4(^1D)$ 3d configuration; the three potential pairs of "blended" levels are the ($^2D_{5/2}$, $^2P_{3/2}$); ($^2D_{3/2}$, $^2P_{1/2}$); and ($^2S_{1/2}$, $^2F_{5/2}$) where the first level of each pair is the designation used by Feldman et al. (1973) in our Tables 1 and 3. The theoretical wavelength calculations of Feldman et al. (1973) cannot distinguish between the possibility of a single level or two levels. Their laboratory observations cannot distinguish between these possibilities in the fluorine isoelectronic sequence beyond about S VIII for the first two pairs of levels and beyond about Sc XIII for the third pair of levels. For lower members of the isoelectronic sequence both levels give rise to individual observable lines.

The effect of including the three additional Fe XVIII levels gives rise to the possibility of five blended lines, those at 14.200Å and 14.419Å for the first pair of levels, those at 14.150Å and 14.361Å for the second pair of levels, and that at 14.255Å for the third pair of levels. (We have used Feldman et al.'s (1973) wavelengths.) The possibility of blends with the line at 14.419Å have already been included in Tables 1 and 3 (and in the calculation of relative collision strength in Table 3). The line arising from the $(^1D)3d\ ^2P_{3/2}$ level at 14.419Å contributes slightly less than 1/2 of the calculated relative collision strength (which is too low by a factor of 5) of the line we observe at 14.422Å. Thus its existence or nonexistence cannot reconcile this particular calculation with the observation. The first possible blend listed above is the most important ($^2D_{5/2}$, $^2P_{3/2}$) since we have used the $^2D_{5/2}$ line at 14.200Å to normalize all other collision strengths. The presence of the $^2P_{3/2}$ transition , with an intensity given by the Bethe approximation and Cowan's oscillator strength, has the effect of increasing the collision strength for the 14.200Å line by about 50%. If this were the only "blended" transition, it would uniformly decrease all of the other 2p-3d and 2p-3s relative collision strengths by a factor of 1.5. While obviously changing the results of a comparison of the Bethe calculation and observations, it would not result in overall better agreement between them.

Furthermore, there is no reason to expect only one "blended" level will be significantly populated without the other possible "blended" levels being populated. We have therefore carried out a calculation assuming all levels that may exist will be populated according to Bethe approximation. Again, the net result is the same. Although individual lines change the ratios of the calculated to observed relative collision strengths, the overall agreement is not improved by these procedures. Therefore, we believe, even with the inclusion of other potential Fe XVIII levels which could give rise to additional "blended" lines, the agreement between the calculated relative collision strengths using Cowan's oscillator strengths and the modified Bethe approximation, and the observed collision strengths is not improved. Presumably the discrepancy results for the reasons given in the last sub-section. At the present time we endorse Feldman _et al._'s (1973) designations for the various transitions, which are based on a study of the entire isoelectronic sequence, until evidence that the other potential "blended" $2p^4$ (^1D) 3d levels are of importance is produced.

h) Comparison with a Previous Analysis of Fe XVIII

Before leaving the subject of collision strengths it should be pointed out that Parkinson (1975) has analyzed six Fe XVIII lines observed in his high resolution X-ray spectra taken from a rocket. His strongest Fe XVIII line (14.2Å) had but 60 counts, his weakest 12, and the four remaining lines 24 counts each, after background subtraction. Consequently, the accuracy of the line intensities and the collision strengths derived by Parkinson are limited by the relatively poor statistics. Parkinson (1975) uses equations essentially similar to our equations (1) and (10) to evaluate the oscillator strength for his observed transitions; however, he neglects the branching ratio, B_{ji}, in his formulation. (He also adopts Tucker and Koren's (1971) nonstandard usage of the definition of the collision strength incorporating the statistical weight factor.) In Parkinson's (1975) Table X he presents his inferred _oscillator_ strengths for Fe XVIII which are all a factor of ~ 100 smaller than would be estimated from the analogy with Fe XVII as well as from Cowan's calculations (which were not available to Parkinson). Therefore we have redone his Fe XVIII calculation using only information presented in his paper for abundances, ionization equilibria, differential emission measure and line intensities. With this information we have attempted to rederive his values of the Fe XVIII oscillator strengths. We find values almost exactly a factor of 100 higher than those given by Parkinson. In order to check our calculation, we performed a similar calculation, again using only Parkinson's data and assumptions, for his 15.01Å line of Fe XVII and obtained a result that agreed with his to within $\lesssim 20\%$. Therefore, we assume an error in arithmetic by a factor of 100 was made by Parkinson, and to obtain values properly reflecting his analysis both the deduced values of his oscillator strengths and collision strengths for Fe XVIII (only) should be multiplied by a factor of 100. Taking into account the limitations in statistical accuracy of Parkinson's intensity ratios for the six Fe XVIII lines he observed, these ratios are in agreement with ours listed in Tables 1 and 2.

V. Fe XVIII AND Fe XVII RELATIVE X-RAY INTENSITIES

Fe XVII X-radiation between ~ 13.5 and 17.5Å represents the largest energy flux emanating from the solar corona for any ion in this wavelength range. This wavelength range is important because many solar X-ray measurements, some with relatively poor spectral resolution, have obtained data in this spectra region. For example, both the S-054 (Krieger 1976) and S-056 (McKenzie, private communication) X-ray telescopes flown on Skylab had at least one filter position in which one or more of the Fe XVII X-ray lines accounted (by calculation) for ≥ 20% of the energy deposited on their film recording the solar image in X-rays at coronal temperatures often found in active regions. Fortunately, with recent theoretical (Loulergue and Nussbaumer 1975) and experimental (Walker, Rugge, and Weiss 1974a, Parkinson 1975, Hutcheon, Pye, and Evans 1976) work a proper assessment of the amount of energy emitted by the Fe XVII ion can be made for essentially any optically thin astrophysical plasma. As has been stated earlier in this paper, this is not the situation in any sense for Fe XVIII. No detailed theoretical work has been carried out to date on Fe XVIII fluxes and this paper is the first experimental work to present a relatively accurate and detailed examination of Fe XVIII X-radiation from the corona. For this reason we will compare the relative energy flux of the total Fe XVII and Fe XVIII X-ray emission from the solar corona. Relatively little X-ray flux is emitted by either ion outside the 13 to 17.5Å region, compared to the energy emitted within this wavelength region.

We have used eight spectral scans, taken over the two day period 1969 March 20 and 21, to obtain the energy ratio of the Fe XVIII flux relative to both the strongest Fe XVII transition at 15.01 Å ($2p$-$3d\,^1P_1$) and to the total Fe XVII flux in the 13 to 17.5Å wavelength interval. These data, along with other related data, are presented in Table 5. A variety of solar conditions prevailed during the individual scans as can be seen from intensity of the Fe XVIII line at 14.2Å (in counts) and the Fe XVIII (14.2Å) to Fe XVII (15.01Å) energy flux ratios. As has been mentioned before, the four consecutive spectra taken beginning about 1442 UT on 1969 March 21 followed a class 1B flare which occurred ~ 1330 UT. Thus, the change in the "spectral hardness" of the spectra can be determined as a function of time after the flare from the data presented in the table.

As can be seen from the fourth and fifth columns of Table 5, a non-negligible amount of X-radiation may originate from Fe XVIII ions, especially during and after flares as well as from "hot" active regions. Thus, an accurate estimate of Fe XVIII X-radiation produced by hot, optically thin astrophysical plasmas is essential to precise calculations of energy loss and spectral output of such plasmas as well as to the interpretation of broad-band or low resolution X-ray pictures of the sun.

TABLE 5
Comparison of Fe XVIII and Fe XVII Intensities

Date (1969)	Fe XVIII (14.2Å) Intensity (Counts)	$\frac{E\ (14.2Å)}{E\ (15.01Å)}$	$\frac{E\ (\text{Fe XVIII})}{E\ (15.01Å)}$	$\frac{E\ (\text{Fe XVIII})}{E\ (\text{Fe XVII})}$
20 March				
0528 U.T.	44	0.04	0.23	0.06
0615 U.T.	131	0.09	0.56	0.15
21 March				
0419 U.T.	342	0.14	0.82	0.22
0423 U.T.	365	0.13	0.77	0.20
1442 U.T.	612	0.24	1.4	0.38
1446 U.T.	639	0.21	1.2	0.32
1450 U.T.	546	0.17	1.0	0.26
1454 U.T.	307	0.15	0.90	0.23

VI. SUMMARY AND DISCUSSION

In this paper we have presented the first accurate and comprehensive measurements of the wavelengths and relative intensities of the strongest X-ray lines of Fe XVIII emitted by the solar corona. The Fe XVIII data were obtained from eight relatively high resolution X-ray spectra of the sun taken from a Bragg crystal spectrometer flown on the OV1-17 satellite on 1969 March 20 and 21. We have definitely identified eighteen Fe XVIII coronal lines or line blends and compared their wavelengths with the best available values obtained from measurements of hot laboratory plasmas. The agreement between the solar and laboratory wavelengths is excellent. We have used the measured Fe XVIII relative intensities to deduce the relative effective collisions strengths for this ion and essentially all of the higher z members of the fluorine isoelectronic sequence since $z^2 \Omega \simeq$ constant for the higher z values along an isoelectronic sequence. The use of these deduced relative collision strengths in collisional excitation calculations was mentioned and the potential complicating effects of cascade processes were discussed in detail.

The OV1-17 deduced relative collision strengths were compared to calculations of the same quantities using the modified Bethe approximation. In all cases the 2p-3s calculated collision strength ratios were significantly smaller than the values obtained from the OV1-17 satellite Fe XVIII line intensity measurements. We concluded this was evidence for the existence of strong cascading effects from the 3p to the 3s levels in Fe XVIII. While agreement between the Bethe approximation calculations and the OV1–17 relative collision strengths was better for the 2p-3d transitions than for the 2p-3s, it was not nearly as good as the accuracy we believe is inherent in Cowan's calculated oscillator strengths. Reasons for this discrepancy were presented as were potential complications to the analysis from line blends. It was concluded that potential line blending could not remove the discrepancy between the calculated values and the values deduced from the OV1-17 X-ray spectra.

All eight X-ray spectra were used to compare the X-ray energy flux of the corona in Fe XVIII to that in Fe XVII for a variety of solar conditions. It was concluded that Fe XVIII X-radiation is non-negligible compared to that of Fe XVII, especially from hot active regions and, presumably, from flares.

In the work presented in this paper we have used only relative intensities rather than absolute intensites for the Fe XVIII emission lines. There are several important reasons for this. First, the relative efficiency of the OV1-17 KAP crystal spectrometer, over a short wavelength region, is substantially better known than the absolute efficiency. However, we believe we know the absolute efficiency to within a factor of two. Second, in order to derive absolute Fe XVIII line intensities the differential emission measure function, M(T) (eqn. (3)), must be derived. Craig and Brown (1976) have shown that the problem of determining differential emission measure is ill-conditioned and may not lead to unique solutions.

The third problem, for Fe ions in general, is with the G(T) function or, more precisely, with the ionization equilibrium part of its calculations, i.e., a_{Zz} (see eq. 2). Until very recently Jordan's (1969, 1970) calculations of $a_{ZZ}(T)$ have been almost universally used in coronal calculations. Recently, however, Jacobs et al. (1977) have included additional autoionization terms in a detailed ionization equilibrium calculation which have the major effect of shifting the peak of the ionization equilibrium curves as calculated by Jordan (1969, 1970) toward lower temperatures by $\sim 1.5 \times 10^{6}$ ^{o}K for Fe XVIII. Until it becomes clear which, if either, of the two calculations are correct for Fe ions, it appears to be a thankless task to attempt a proper evaluation of the absolute intensities of our Fe XVIII (or Fe XVII) line intensities. This statement probably applies equally well to other recent and future Fe ion line measurements in the X-ray region.

In any case, we believe the most valuable contribution experimental measurements can make to the understanding of Fe XVIII line emission from the solar corona are the relative intensities of these lines, given in Tables 1 and 2. It was precisely these observed intensity ratios, for Fe XVII, that led to a reassessment of the theory (Pottasch 1966) and the subsequent theoretical understanding of that complex ion (Loulergue and Nussbaumer 1975). A similar understanding of Fe XVIII awaits the difficult and tedious calculation of the collision strengths similar to that performed by Loulergue and Nussbaumer (1973) for Fe XVII.

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